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REMARKS/ARGUMENTS

Claims 1-30 were pending of which Claims 1-10 and 18-30 were rejected and Claims 11-17 were allowed. (Note: The Office Action Summary indicated that Claims 11-17 were subject to a restriction and/or election requirement, while the Detailed Action stated that these claims were allowed. Since the Detailed Action gives no support for a restriction and/or election requirement, the Applicant assumes that the Examiner intended to allow Claims 11-17).

Claim Rejections – 35 U.S.C. §103

Claims 1-4, 9, 10, 18, 20, 21 and 23-30 were rejected under 35 U.S.C. §103(a) as being unpatentable over Stevens in view of Kitch et al. and Yamadai.

The principal reference cited was Stevens. The Examiner referenced col. 14, lines 18-31, of Stevens, which he stated “discloses a method of forming a titanium layer on a substrate where a substrate is placed in a deposition chamber comprising a source of titanium, depositing the titanium layer onto the substrate in an atmosphere that comprises hydrogen.” The process involved in this section of Stevens is chemical vapor deposition. The Examiner recognized this and noted that “Stevens does not disclose forming the titanium layer by physical vapor deposition (PVD) and having a <002> orientation.” Claims 1 and 18 recite “depositing the titanium layer onto the substrate by physical vapor deposition.” Claim 20 recites “sputter depositing the titanium layer onto the substrate.” Claim 23 recites “placing a substrate in a physical vapor deposition chamber” and “igniting a physical vapor deposition plasma in the chamber.”

The last-quoted statement about Stevens is not accurate. At col. 14, line 53, to col. 15, line 42, Stevens does describe a *PVD process* that includes forming titanium layers. In both cases, the process uses argon ions but in neither case does the atmosphere include hydrogen (see col. 14, lines 63-65; col. 15, lines 12-15).

The Examiner cites Kitch et al. as teaching “depositing the titanium layer (13) onto the substrate by physical vapor deposition (PVD) in an atmosphere that comprises argon” and Yamadai as teaching “a titanium layer (3) with a <002> orientation, ... sputter deposited on a substrate (1).” The Examiner recognized that neither Kitch et al. nor Yamadai describes sputter-depositing a titanium layer in an atmosphere that comprises hydrogen.

Thus none of the three references describes depositing a titanium layer by PVD in an atmosphere that contains hydrogen.

The Examiner seeks to overcome this by citing Stevens in combination with Kitch et al. and Yamadai. The problem is that this combination of references does not meet the standards required for an obviousness rejection. The claims in this case recite "sputter-depositing" and "physical vapor deposition." A person of skill in the art who sought to combine these references would use the teachings of Stevens that relate that relate to *sputtering (PVD)*, none of which refer to the inclusion of hydrogen in the atmosphere. The section of Stevens cited by the Examiner describes a *chemical* vapor deposition process (CVD) (see col. 13 line 380). Attached as Exhibit A are pages 150-151 and 443-444 of Wolf, *Silicon Processing For The VLSI Era*, which describe the basic characteristics of CVD and PVD processes, respectively. As these pages indicate, chemical vapor deposition is very different from physical vapor deposition. Given the clear distinctions between these two types of processes, a person of skill in the art would have no reason to think that a mechanism that yields a particular result in a CVD process would yield the same result in a PVD process.

With regard to the Examiner's citation of col. 1, lines 8-11, of Kitch et al. on page 3 of the Office Action, a person skilled in the art would not "modify Stevens by forming the titanium layer by physical vapor deposition (PVD) as taught by Kitch et al." because Stevens himself teaches a PVD process. Stevens' PVD process teaches away from the combination proposed by the Examiner because it does not involve the use of a hydrogen-containing atmosphere.

In summary, a person skilled in the art would not be motivated to apply Stevens' teachings relative to CVD in the PVD processes described by Kitch et al. and Yamadai. The use of a hydrogen-containing atmosphere in a CVD process would not be predictive of the results in a PVD process, and Stevens does not even claim that the use of hydrogen results in any particular crystal structure in the deposited titanium layer. Thus, a person of skill would have absolutely no reason to think that including hydrogen in the atmosphere of a PVD process would provide a titanium layer with a preferred crystal structure.

Furthermore, if such a person were motivated to apply *any* of Stevens' teachings to Kitch et al. and Yamadai, it would be those that pertain to PVD, which suggest the use of an argon atmosphere without hydrogen.

Claim 2-4, 9 and 10 depend from Claim 1; Claim 21 depends from Claim 20; and Claims 24-30 depend from Claim 23. Therefore, Claims 2-4, 9, 10, 21, 24-30 are allowable over Stevens in view of Ketch et al. and Yamadai for at least the same reasons.

Claims 5 and 8 were rejected under 35 U.S.C. 103(a) over Stevens in view of Kitch et al. and Yamadai and further in view of Freeman et al. Freeman et al. was cited as showing "the gas mixture comprising at least 4 mole percent hydrogen (col. 4, lines 7-57)."

Claims 6 and 7 were rejected under 35 U.S.C. 103(a) over Stevens in view of Kitch et al. and Yamadai and further in view of Kaloyeros et al. Kaloyeros et al. was cited as showing "the power used in the sputtering method having a power density of between 0.01 W/cm² and 10 W/cm² (col. 10, lines 60-67; col. 11, lines 1-17)."

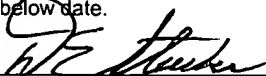
Claims 19 and 22 were rejected under 35 U.S.C. 103(a) over Stevens in view of Kitch et al. and Yamadai and further in view of Hsu et al. Hsu et al. was cited as showing "the aluminum layer having a FWHM of 1.5 degrees (col. 3, lines 11-65)."

Claims 5-8 depend from Claim 1, Claim 19 depends from Claim 18, and Claim 22 depends from Claim 20. None of the Freeman et al., Kalyeros et al., and Hsu et al. patents overcome the defects, described above, in the combination of Stevens, Kitch et al., and Yamadai as regards the patentability of Claims 1, 18 and 22. For example, Freeman et al. does not even refer to a titanium layer; Kaloyeros et al. deals with a CVD process; and Hsu et al. seems to teach depositing a titanium layer by CVD (although this is not entirely clear).

For the above reasons, Applicants respectfully request allowance of Claims 1-30. Should the Examiner have any questions concerning this response, the Examiner is invited to call the undersigned at (408) 982-8200, ext. 1.

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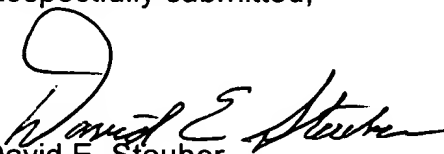


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5/24/04

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**SILICON PROCESSING
FOR
THE VLSI ERA**

**VOLUME 1:
PROCESS TECHNOLOGY
Second Edition**

**STANLEY WOLF Ph.D.
RICHARD N. TAUBER Ph.D.**

**LATTICE PRESS
Sunset Beach, California**

6.1 BASIC ASPECTS OF CHEMICAL VAPOR DEPOSITION

A CVD process can be summarized as consisting of the following sequence of steps:

1. A given composition of reactant gases (frequently diluted by mixing with an inert *carrier* or *diluent* gas) is introduced by forced convection into a reaction chamber. These gases move in the chamber from the inlet to the outlet in what is referred to as the *main gas-flow region*, as shown in Fig. 6-1a). As these gases flow through the chamber, they come into the vicinity of the wafers that have been loaded within it.
2. The reactant-gas species are transported to the wafer surface through a sector of the gaseous volume referred to as the *boundary layer*. This transport occurs by gas-phase diffusion. That is, a boundary layer in the gas exists between the main gas-flow region and surface of the wafer (Figs. 6-1a and b).
3. The reactants are adsorbed on the substrate surface, and these adsorbed species are referred to as *adatoms*.
4. The adatoms undergo surface migration to the growth sites, where the *film-forming chemical reactions* take place. These reactions are responsible for creating the solid film and gaseous by-products. In some cases, a gas-phase reaction leading to the formation of film precursors (or even the final product) occurs somewhere in the gas prior to the reactants reaching the substrate surface.
5. The gaseous by-products of the reaction are desorbed from the surface. These products must diffuse through the boundary layer near the surface into the main gas-flow region, and from there they are removed from the chamber as the main gas-flow moves toward the outlet.

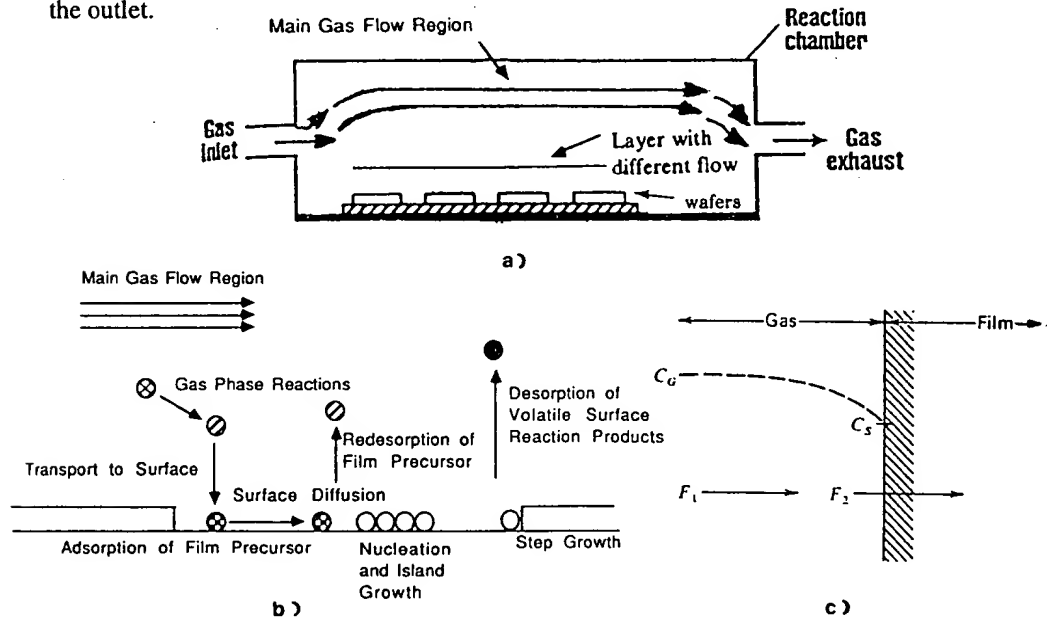


Fig. 6-1 a) CVD reaction chamber with gases flowing into and out of it. b) The five sequential steps of a CVD process. c) Grove's model of the CVD process depicting the transport and reaction fluxes F_1 and F_2 .

Energy to drive the film forming reactions is supplied by one or more of the following energy sources: thermal energy; photons; or electrons (with thermal energy being the most common energy source used). A variety of chemical reaction types are employed in CVD to fabricate the many kinds of films needed in ULSI structures, including pyrolysis (thermal decomposition), reduction, oxidation, disproportionation, and hydrolysis of the reactants.

Several other practical aspects of CVD processes should be mentioned. First, the deposition time needed to form the film with the desired thickness must be sufficiently short to permit adequate wafer throughput. Second, the process temperature must be low enough so that it does not adversely impact the stability of previously deposited layers (e.g., low-melting-point metal layers such as Al). Third, the CVD process should not allow by-products of the reactant gases to become incorporated into the growing films (but this is sometimes unavoidable, such as when a significant amount of hydrogen is incorporated in PECVD silicon nitride films - see Sect. 6.5).

As noted in Step 4, the chemical reactions leading to the formation of the solid that makes up the deposited film may, in practice, take place not only on (or very close to) the wafer surface (*heterogeneous reaction*), but also in the gas phase (*homogeneous reaction*). Heterogeneous reactions are preferred, as such reactions occur selectively only on heated surfaces, and produce good quality films. Homogeneous reactions are undesirable because they form solid clusters of the depositing material in the gas phase. These clusters can rain down on the film growing on the wafers, which may cause defects in the depositing film and other film problems including poor adhesion and low film density. In addition, homogeneous reactions also consume reactants and thus can cause the deposition rate to decrease. As a result, one important characteristic of a chemical reaction for CVD application is the degree to which heterogeneous reactions are favored over gas-phase reactions.

6.1.1 Grove's Simplified CVD Film-Growth Model

Since the aforementioned steps of a CVD process are sequential, the one which occurs at the slowest rate will determine the overall rate of the film deposition. This slowest step is referred to as the *growth-rate-limiting step*. Since high growth rates are essential for making a deposition process economically feasible, the determination of the growth-rate-limiting step can be valuable. Knowledge of which of the five steps is the slowest may allow process modifications to be developed to speed up that step, and perhaps increase the overall deposition rate.

A model that allows the growth rate of CVD films to be predicted would also be a useful tool for developing CVD processes. However, deriving a mathematical relationship which predicts CVD growth rates based on all five steps of the process sequence has proven difficult, even up to this time. Instead, less complex growth-rate models have been created, based on the observation that the steps of the CVD process can be grouped into two categories: 1) those that occur in the gas phase (*gas-phase processes*); and 2) those that occur on the substrate surface or chamber-wall surface (*surface processes*). For example, by using this observation, Grove⁵ developed a simple CVD growth-rate model in 1966 that is still widely used. Grove's model assumes that *only one of the gas-phase growth steps* (i.e., the transport of the reactants across the boundary layer, Step 2 or *only one of the surface processes* (i.e., the surface chemical reaction, Step 4) *is the rate-limiting step*. Despite these simplifying assumptions, Grove's model explains many phenomena observed in CVD processes and predicts many film growth rates quite accurately.

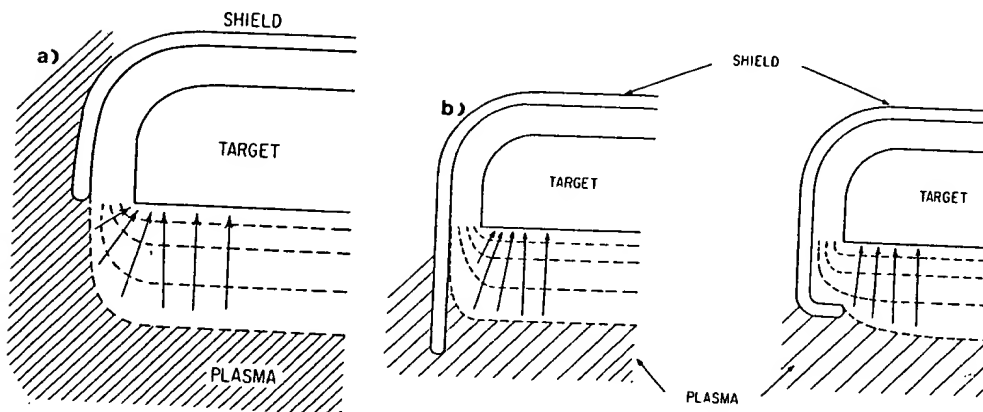


Fig. 11-7 (a) Potential distribution in vicinity of cathode shield (b) Reducing rim effect by extending cathode shield. (c) Reducing rim effect by wrapping shield around the cathode.⁸ From L. Maissel and R. Glang, Eds., *Handbook of Thin Film Technology* 1970. Reprinted by permission of McGraw-Hill Book Co.

dark space however, the ion production rate becomes reduced, and the voltage across the electrodes must rise to increase the secondary electron emission. Such a glow is known as an *obstructed glow*. In most practical sputter deposition systems the glow is obstructed. That is, in order to most effectively collect the sputtered material onto the substrate, the anode (on which the wafers are sometimes mounted) is placed as close to the cathode as possible (typically just far enough away to avoid extinguishing the negative glow).

It is typically necessary to insure that sputtering is allowed to occur only at the front side of the target, as the backside contains cooling coils and attachment fixtures which are definitely not to be sputtered. To guarantee that no sputtering takes place except from desired surfaces, a shield of metal (at a potential equal to that of the anode) is placed at a distance less than the Crookes dark space at all other cathode surfaces (Fig. 11-7). Since no discharge will occur between two electrode surfaces separated by less than this distance, such shielding (termed *dark-space shielding*) is effective in preventing sputtering from unwanted cathode surfaces.

11.3 THE PHYSICS OF SPUTTERING

When a solid surface is bombarded by atoms, ions, or molecules, many phenomena occur. The kinetic energy of the impinging particles largely dictates which are the most probable events. For low energy particles (<10 eV), most interactions occur only at the surface of the target material. At very low energies (<5 eV) such events are limited to reflection or physisorption of the bombarding species. For low energies which exceed the binding energy of the target material (5–10 eV), surface migration and surface damage effects can take place. At much higher energies (>10 keV), the impinging particles travel well into the bulk of the sample before slowing down and depositing their energy. Thus, such particles are most likely to be embedded in the target, and this mechanism is the basis of ion-implantation. At energies between the two extremes, two other effects also arise: 1) some fraction of the energy of the impinging ions is transferred to the solid in the form of heat, and lattice damage; and 2) another fraction of such energy causes atoms from the surface to be dislodged and ejected into the gas phase (*sputtering*).

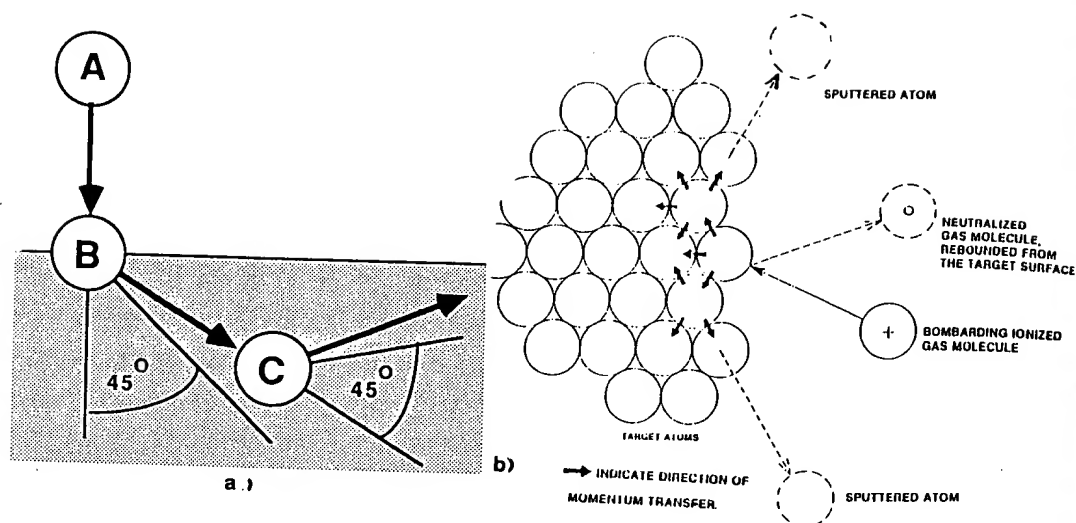


Fig. 11-8 (a) Binary collision between atom A and B, followed by a binary collision between atom B and C. (b) Collision process responsible for sputtering and fast neutral generation.

11.3.1 The Billiard Ball Model of Sputtering

The exact mechanisms which lead to the ejection of atoms under ion bombardment are not known, and a comprehensive theory of sputtering is not likely to be developed in the near future since many parameters are involved. These include the kinetic energy of the ions, lattice structure, and binding energy of lattice atoms. Some of the details, however, are reasonably well understood and can be aptly described with a relatively simple momentum-transfer model. G.K. Wehner, whose theoretical work first established a solid scientific basis for sputtering, often described sputtering as a game of three-dimensional billiards, played with atoms.⁹ Using this analogy, it is possible to visualize how atoms may be ejected from a surface as the result of two binary collisions (Figs. 11-8b and 11-8c) when a surface is struck by a particle with a velocity normal to the surface (e.g., atom A in Fig. 11-8b). Note that a *binary collision* is one in which the primary incoming particle (e.g., atom A) strikes a single object (e.g., atom B in Fig. 11-8b), and gives up a significant fraction of its energy to the struck atom, while retaining the remaining fraction. As a consequence of the collision, atom B may leave the point of impact at an angle greater than 45°. If atom B then undergoes a secondary collision with atom C, the angle at which atom C leaves the secondary impact point may again be greater than 45°. Thus, it is possible that atom C can have a velocity component greater than 90° (and thus be directed toward the surface). As a result, there is a finite probability that atom C will be ejected from the surface as a result of the surface being struck by atom A.

When the directions of sputtered atoms from the surface of polycrystalline materials (and most cathode materials in sputter applications are polycrystalline) are measured for the case of *normal incidence*, it is found that the ejected atoms leave the surface in essentially a cosine distribution. A cosine distribution, however, does not describe the sort of small-angle ejections that would be expected from the simple collision processes described above. Evidently in actual sputtering events, more than two collisions are involved, and the energy delivered by impinging ions *during normal incidence* is so randomly distributed that the effect of the incident momentum vector is lost. Note that the energy range of sputtered atoms leaving the target is